## State of the Art

# Cumulative Energy Demand for Selected Renewable Energy Technologies

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## Abstract

Calculation of Cumulative Energy Demand (CED) of various energy systems and the computation of their Energy Yield Ratio (EYR) suggests that one single renewable energy technology cannot be said to be the best. Due to the difference in availability of renewable energy sources, their suitability varies from place to place. Wind energy converters, solar water heating systems and photovoltaic systems have been analysed for different types of locations. Comparing the general bandwidth of performance of these technologies, however, the wind energy converters tend to be better, followed by solar water heating systems and photovoltaic systems.
Since a major part of the methodology of finding *CED* is very close to that of life cycle assessment and also because of the dominance of environmental impacts caused by the energy demand in the entire life cycle of any product or system, it is suggested that the *CED* can be used as an indicator of environmental impacts, especially in the case of power producing systems.

**Keywords:** Cumulative energy demand; life cycle assessment; energy yield ratio; photovoltaics; solar water heating; wind energy
Abbreviations: CED – Cumulative Energy Demand; EYR – Energy Yield Ratio; LCA – Life Cycle Assessment; Photovoltaics – PV; WEC – Wind Energy Converters

## 1 Introduction

The International Federation of Institutes for Advanced Studies (IFIAS, 1974), and subsequently the Verein Deutscher Ingenieure, define the term Cumulative Energy Demand (*CED*) as: 'The Cumulative Energy Demand states the entire demand, valued as primary energy, which arises in connection with the production, use and disposal of an economic good ...' (VDI, 1997).

Therefore, the *CED* can be understood as an indicator of environmental impacts as far as the depletion of energy resources is concerned.

In comparison with ISO 14040, the methodology of finding *CED* shows common links. While the accounting of material balance can be seen as part of an inventory analysis, the calculation of *CED* may be understood as a rough form of impact assessment.

## 2 Methodology

To obtain the energy demand for the production of a power plant, the whole facility has to be split up into components, sub-components and their respective materials. Using this material balance with specific data for material $ced_{material}$ and energy resources (which are found by process chain analysis and can be obtained through various publications[1]), it is possible to calculate the cumulative energy demand of production $CED_P$:

$$CED_P = \sum_{Components} CED_{P,Components}$$

with

$$CED_{P,Component} = \sum_{Material} \left[ced_{material} \cdot m_{material}\right] \cdot F_P$$

The energy demand of production processes (e.g. assembly of parts) is taken into account by multiplication of the material-based energy demand with a production-factor $F_P$ (Wagner & Wenzel, 1997).

Manufacturing factors have been assigned to the materials depending upon their form of usage in the plant. It is quite possible to find two different factors for the same material in different components, the reason being that the amount and nature of processing differs from case to case.

Here, the available data of energy consumption for transportation has also been included. In these cases, the most

[1] compare (Wagner & Wenzel, 1977)

common mode of transportation for a certain type of component in the respective country is considered. However, because of the large distances in India, a sensitivity analysis has been carried out to find the possible variation in *CED* due to transportation. The following formula using the distance *d* and weight *m* has been used to find the energy demand for transportation:

$$CED_{Transport} = ced_{Transport} \cdot d \cdot m$$

Data for the transport-processes are taken from various sources (GEMIS, 1995; LUFTHANSA, 1996; FRISCHKNECHT et al., 1994).

The energy demands for the disposal and recycling of plant-material, where available, have also been included. The total energy demand has been found by:

$$CED_{Total} = CED_{Production} + CED_{Utilisation} + CED_{Disposal} + CED_{Others}$$

Detailed material and energy balances have been used to obtain the total *CED*. The energy contents of silicon wafers and modules have been taken from suitable literature (KATO et al., 1997; KOHAKE et al., 1997). The specific energy contents of materials have been considered to be equal for both countries.

The average climatic data of several years has been used for the calculations in India in order to avoid the possibility of misleading results due to a favourable or unfavourable climate in one particular year. Unlike Germany, there is a wide range of climatic conditions in India. The climatic classification of India into six climatic zones as performed by (BANSAL & MINKE, 1995) has therefore been taken as a reference and one representative city of each climatic zone has been analysed assuming no variation of climatic conditions within one zone. A detailed description of the approach can be found in (MATHUR & BANSAL, 1998).

The method of finding the annual energy output of the systems is not the same for all of the technologies. For wind energy, the wind energy power curve provided by the manufacturer has been used. For the solar hot water system in India, a simulation has been carried out to find the annual output. For photovoltaic systems, a lifetime efficiency of conversion has been considered with the minimum value of average daily radiation being used to satisfactorily serve this purpose even during the low radiation days. For such systems a minimum output is taken as a basis for the calculation of a module area.

For final evaluation of the energy systems Energy Yield Ratio (*EYR*) as relationship of produced energy and total Cumulative Energy Demand has been used:

$$EYR_{net,physical} = \frac{W_{net,physical}}{CED_{total}}$$

The above mentioned formula is one possible definition of *EYR*, comparing the physically produced energy with the primary energy demand over the lifetime of the plant. Other definitions only use the Cumulative Energy Demand for production of the plant or convert the output energy to a primary energy equivalent by using an average potential efficiency (HAGEDORN, 1992, KOHAKE et al., 1997).

The system boundary considered for this report primarily encompasses the direct energy demands through materials, manufacturing and assembly processes, operational energy demand, transportation and disposal. As our aim is the conservation of energy resources (in the original meaning of the word), we do not take into account renewable energy resources (i.e. the physical energy of insolation) that are replenished continuously or replaced after use through natural means.

## 3 India

In spite of having a low conversion efficiency for the process chain of primary to end energy, 74.9% of the electricity produced in India comes from coal based power plants (POWER, 1998); hence a wind energy system option needs to be compared with a coal power plant for generation of electricity. Due to frequent power failures and load-shedding, the small inverter-accumulator systems are very common in medium class Indian houses as a stand-by power supply option. These systems consume a lot of electricity for the charging of an accumulator. Consequently, photovoltaic charging systems are considered as a replacement of the charging from the grid. In addition, a solar hot water system has been compared with an electric hot water system since such systems are very commonly used in India.

### 3.1 Wind energy converters

Wind energy converters (*WEC*) are being considered as a promising clean alternative to the conventional coal power plants that enjoy a share of about 75% (POWER, 1998) in the electricity mix of India. Out of about 50 sites identified as having a potential for the generation of electricity from wind, three energy sites located in different climatic and different surrounding conditions have been chosen. From the six climatic zones of India (BANSAL & MINKE, 1995), only three climatic zones have a considerable potential of wind energy. Sites have been selected carefully to ensure that there is one site of each of the three types of locations, namely coastal, near coastal and inland sites. These are Rameswaram, Bamanbore and Sultanpet, respectively.

**System Details**

Out of the wide range of wind energy converters, the largest *WEC* of 1.5 MW capacity produced by a German manufacturing company with a hub height of 67 meters and a rotor diameter of 66 meter has been considered in this report. However, it follows from (PICK, 1998) that the variation in Energy Yield Ratio for different types of *WEC* is only within 10%.

General assumptions used in this analysis according to (BUNK, 1998) are:

- The selected sites represent the average wind condition of their respective climatic zones with no or little variation within permissible limits.
- Wind velocity distribution within a year and within a month follows Weibul's distribution.
- The velocity profile of wind velocity with altitude is exponential in shape.
- All the components except the foundation are made at a plant situated in northern Germany and transported to India.
- The machinery is transported by ship to the nearest port in India and thereafter by railway to the site.
- Lifetime of a plant is 20 years.
- A coating on the rotor blades is required again after 10 years.

**Material and Energy Balance**

For finding the material and energy balances, the *WEC* has been considered to be divided into six parts. Separate material and energy balances for each of the six parts were prepared. To take the energy consumption for the manufacturing processes into account, manufacturing factors have been assigned to individual materials using the factors of (WAGNER & WENZEL, 1997) with suitable modifications for Indian conditions, wherever found necessary. Energy consumption for transportation has also been taken into account as the wind energy converters are manufactured at the plant located in the northern part of Germany and from there transported to India for erection on site. **Table 3.1.1** gives the break-up of *CED* of *WEC* including transportation and maintenance.

The *CED* for the three selected sites is different for the following reasons:

- Distance for the transportation of equipment is different.
- The type of foundation depends upon the nature of soil at the site. Normally, a deep foundation is required at coastal sites that has a higher *CED*.

**Energy Harvest**

For calculating the energy output or energy harvest the wind energy data for the three sites of India have been taken from (MANI, 1993). A three year average for Rameswaram and Bamanbore, and a five year average for Sultanpet has been considered due to availability. Hellmann's exponent that governs the relationship between wind velocity and altitude has been found by using wind velocity at heights of 10 m and 20 m. The power curve as a characteristic of each type of system is provided by the manufacturer and has been used in conjunction with the yearly average wind velocity to calculate the power output. Harvest calculations, however, have also been performed using the monthly figures for average velocity and Weibul parameters, although the difference in the results is less than 1%. About 0.35% of the energy harvest is used by the system itself for different devices and controls. Therefore, the net harvest is 99.65% of the total harvest. The harvest for Rameswaram is highest, 6033 MWh per year, while the lower figure is for Sultanpet, 1846 MWh per year.

**Energy Yield Ratio**

The *EYR* of the considered *WECs* range from 9.59 to 31.11. Details of the calculations can be found in **Table 3.1.2**.

**Table 3.1.2:** Yearly Energy Harvest, Payback and *EYR* of *WEC* in India

| | coastal (Rameshwaram) | near coast (Bamanbore) | inland (Sultanpet) |
|---|---|---|---|
| Energy harvest (kWh/a) | 6054447 | 2128941 | 1852798 |
| Energy harvest (net) | 6033256 | 2121490 | 1846313 |
| $W_{net}$ (GJ/a) | 21719 | 7637 | 6646 |
| *CED* (GJ) | 13960 | 13742 | 13852 |
| $EYR_{net,\ physical}$ | 31.11 | 11.11 | 9.59 |

**Table 3.1.1:** Break-up of *CED* (incl. manufacturing-processes) of 1.5 MW wind energy converter

| | coastal | | near coast | | inland | |
|---|---|---|---|---|---|---|
| component group | energy content (GJ) | % | energy content (GJ) | % | energy content (GJ) | % |
| rotor blades | 1147 | 8.2 | 1147 | 8.3 | 1147 | 8.3 |
| generator | 2877 | 20.6 | 2877 | 20.9 | 2877 | 20.8 |
| rest of machinery | 1814 | 13.0 | 1814 | 13.2 | 1814 | 13.1 |
| tower | 3774 | 27.0 | 3774 | 27.5 | 3774 | 27.2 |
| grid connection | 1512 | 10.8 | 1512 | 11.0 | 1512 | 10.9 |
| foundation | 1493 | 10.7 | 1350 | 9.8 | 1350 | 9.7 |
| assembly | 402 | 2.9 | 402 | 2.9 | 402 | 2.9 |
| transportation | 743 | 5.3 | 657 | 4.8 | 746 | 5.4 |
| maintenance incl. transportation | 23 | 0.2 | 33 | 0.2 | 55 | 0.4 |
| *CED* | 13960 | 100.00 | 13742 | 100.00 | 13852 | 100.00 |

### 3.2 Photovoltaic system for stand-by accumulator

**System Details**

Single-crystalline photovoltaic modules are manufactured in India by private and semi-government producers. The Central Electronics Limited *CEL*, Sahibabad is a semi-government organisation where silicon wafers are processed to make solar cells and subsequently photovoltaic modules. The wafers are indigenously manufactured and are also imported from foreign countries to meet the manufacturing demand. Following are the specifications of a module produced by *CEL*:

- Type: Single crystalline
- Output: $35W_{peak}$
- Cell efficiency: 13% at standard test conditions (1000W radiation, 25°C temperature and air density 1.51 kg/m$^3$)
- Module dimensions: 1006 X 398 mm.

A 2 kWh capacity accumulator has been considered to meet the electricity requirement during grid supply failure. This requirement has been estimated to be 1 kWh per day.

The following assumptions are made in calculations for *PV* systems:
- Lifetime conversion efficiency of *PV* modules: 5%
- Lifetime of modules: 20 years
- Replacement of glass cover is required after every 7 years

**Material and Energy Balance**

The energy consumed for the processing of wafers into modules has been taken from the actual measurements at *CEL*. Due to proprietary reasons, more detailed data cannot be given, hence a single final figure has been used. Since the cleaning of dust and deposits is performed manually for small and medium size systems, no other energy consumption for maintenance is needed. **Table 3.2.1** presents the total energy demand for the photovoltaic charging system of a household accumulator. The value of *CED* is different for different places as the module area required for the photovoltaic charging depends upon the radiation. One representative city of each climatic zone has been chosen and a module area has been calculated for the minimum daily radiation condition so that the system works even in the low radiation days. In order to have an idea of the range, the maximum and minimum *CED* cases have been selected from the six cases of different climatic zones.

A sensitivity analysis has been carried out to find the variation in *CED* due to the difference in the distances for transportation. It shows a possible variation up to 0.08% of the total *CED* for transportation by railways and 4.3% for the same by truck.

**Energy Yield Ratio**

The Energy Yield Ratio of the photovoltaic charging system can be found as the ratio of the energy produced to the primary energy input as the *CED* of a photovoltaic system. This ratio is considered as $EYR_{physical}$ for the scenario, as given in **Table 3.2.1**.

Taking into consideration the calculation of module area required based on minimum radiation and energy demand for module production, these figures give a low *EYR* ranging from 0.34 - 0.57. However, the $EYR_{primary}$ if calculated could be around unity.

**Table 3.2.1:** Energy balance for *PV* charging system in Indian climatic zones

| Climatic zone | Hot & dry | Moderate | Composite | Cold & sunny | Warm & humid | Cool & cloudy |
|---|---|---|---|---|---|---|
| Rep. city | Ahmedabad | Bangalore | Delhi | Leh | Madras | Srinagar |
| No. of modules required | 10 | 9 | 12 | 15 | 9 | 15 |
| *CED* (MJ) | 51138 | 46024 | 61365 | 76707 | 46024 | 76707 |
| $EYR_{physical}$ | 0.51 | 0.57 | 0.43 | 0.34 | 0.57 | 0.34 |

### 3.3 Solar water heating system

**System Details**

Natural circulation, single-glazed flat plate collectors are the most common type of devices that are used for solar water heating in India.

Dimensions and materials for different parts of the solar water heating system are chosen as per the recommendations of the Bureau of Indian Standards. A collector of 1000 X 2000 mm and a hot water tank of 100 l capacity, as well as all other system components like piping and supporting frames, have been taken into account.

**Material And Energy Balance**

**Table 3.3.1** shows an overview of material and energy balances for this system. The requirement of iron for the support frame of a collector and hot water tank, and also the length of pipes, are situation specific and may vary from study to study. Commonly found values have been considered for the balances. The life of solar water heating systems has been considered to be 15 years and the replacement of copper tubes (risers), aluminium covers, glazing and 50% of insulation after every five years is considered as maintenance due to the hardness in water and typical environmental conditions of Indian cities.

**Table 3.3.1:** Energy balance of solar hot water heating system

| Component group | Energy content (MJ) | % of system |
|---|---|---|
| Collector | 3603 | 36.26 |
| Hot water tank | 1540 | 15.50 |
| Pipe work | 529 | 5.33 |
| Supports | 294 | 2.96 |
| Maintenance | 3970 | 39.95 |
| *CED* | 9936 | 100.00 |

Collector and maintenance have the largest shares in the total *CED*. $EYR_{physical}$ for such systems range from 2.32 for Leh to 7.14 for Ahmedabad for a lifetime of 15 years. A sensitivity analysis has also been carried out for finding the variation in *CED* due to the difference in the distances for transportation. It shows a possible variation up to 0.34% of the total *CED* for transportation by railways and 18.85% for the same by truck.

## 4 Germany

Due to the constraints like time, availability of information, etc. this study has been restricted to few major types of power plants, especially in the cases of wind energy.
Wind energy converters and photovoltaic systems are used for the generation of electricity, whereas various Water Heating Systems find application in the domestic sector.
Unlike India, the climatic conditions in Germany do not vary much so that a detailed investigation has been dispensed with.

### 4.1 Photovoltaic system

**System Details**
All data for this system has been taken from investigations carried out by the Fachhochschule Gelsenkirchen (Kohake et al., 1997; Pust & Deckers, 1997).

The 1 MW photovoltaic power plant is located in Toledo, Spain and consists of three fields with a total of 950 $kW_{peak}$.

The fields are fitted with mono-crystalline cells on oversize-modules and laser grooved, buried contact cells on standard modules, with cell-efficiencies of 12.2% and 15.2%.

The system is assumed to be situated in Germany. The yearly radiation output is consider to be 1000 kWh/m² and the expected lifetime is 25 years.

Though manufacturers do recycle material within their production processes, no credit is taken into account as no reliable data are available and thus making it a conservative estimation.

**Material and Energy Balance, Energy Output and Energy Yield Ratio**
Table 4.1.1 provides an overview of the calculated figures for the power plant situated in Germany:

**Table 4.1.1:** Photovoltaic Power Plant in Germany

| | Unit | |
|---|---|---|
| $CED_P$ | $GJ_{primary}$ | 63200 |
| $CED_U$ | $GJ_{primary}$ | 9500 |
| $CED_{total}$ | $GJ_{primary}$ | 72700 |
| Gross Power Output | MWh/a | 873 |
| Total gross power output | GWh | 21.825 |
| $EYR_{physical}$ | - | 1.1 |

The biggest share of *CED* for the photovoltaic system lies in the material and energy demand of manufacturing. About 87% of the total *CED* can be assigned to this factor.

### 4.2 Wind energy converters

**System Details**
For calculating the yearly energy output three sites have been selected: Coastal, near coastal and inland. A large *WEC* of 1.5 MW with 67 m hub height and 66 m rotor blade diameter, as produced in Germany, has been chosen to be considered in this report. It has been found that the variation in Energy Yield Ratio for different types (500kW and 1500kW) of *WEC* is only within 10% (Pick, 1998).

General assumptions used in this analysis are (Pick, 1998):

- Wind velocity distribution within a year and within a month follows Weibul's distribution.
- The velocity profile of wind velocity with altitude is exponential in shape.
- All of the components except the foundation are made at the plant situated in northern Germany.
- The machinery is transported by truck to the site.
- The lifetime of one plant is 20 years.
- Maintenance of rotor blades (coating) is required after 10 years.

**Material and Energy Balance**
For finding the material and energy balances, the *WEC* has been divided in six parts as already stated in Section 3.1.
The energy consumption for transportation has been taken into account as the wind energy converters are manufactured at a plant located in the northern part of Germany and are then transported to the sites:

The *CED* of the *WEC* varies from 13795 to 13927 GJ. The tower has the biggest share of about 27% - 28%. Another important component group, due to a high content of energy-intensive materials, is the generator with a share of about 21%. The rest of machinery holds a share of about 13% while the foundation and grid connection hold 10%-11%. For assembly, maintenance and transportation, about 8% of the total CED is needed.

**Energy Harvest and *EYR*:**

**Table 4.2.1:** Yearly energy output of *WEC* in Germany

| | site I (coastal) | site II (near coastal) | site III (inland) |
|---|---|---|---|
| $W_{el}$ [kWh/a] | 4086320 | 3204400 | 2497550 |
| $W_{net,el}$ [kWh/a] | 4072018 | 3193185 | 2488809 |
| $W_{net,physical}$ [GJ/a] | 14659 | 11495 | 8960 |
| *CED* | 13816 | 13795 | 13927 |
| *EYR* [-] | 26.53 | 20.83 | 16.08 |

### 4.3 Solar water heating system

By using additional absorber-systems for hot water heating, a part of the fuel consumption of conventional systems can be substituted. Due to the low solar power density these systems are very material intensive. We investigated if a positive energy-balance can still be found when taking the energy demand for the manufacturing of these materials into consideration.

The choice of reference-systems has taken into account the usability of solar-thermal systems in Germany as well as the bandwidth of different types of constructions used in Germany.

#### System Details

The application of solar-thermal power-generation has been divided into water heating for small houses (one to two families) and for big houses (multiple family houses), whereas the construction types are divided into flat-plate collectors and evacuated tube collectors. These systems represent the most frequently used methods on the German market. Due to a high efficiency of about 20%, the evacuated tube collector needs a smaller area than the other systems. All other components aside from collectors are supposed to be of the same type.

#### Material And Energy Balance

Detailed investigation of used materials gives a total mass of collectors for the small systems of 130 kg (SOLVIS), 110 kg (SOLAR DIAMANT) and 90 kg (evacuated tube collector). For all cases the rest of the system increases the mass by another 90 kg.

The big system collector masses are 2900 kg (SOLVIS) and 2300 kg (evacuated tube collector), whereas the rest of the system weighs about 2400 kg.

Further details concerning the plants mentioned and their material balances are included in (WAGNER, 1995).

By using these material balances and data for the specific energy content of materials, the $CED_M$ can be obtained. As there is no data available for assembly of the components and installation of the systems, an estimated additional energy demand of 10% of the material energy demand is chosen.

Furthermore, it is supposed that no energy is required for disassembly and deposition or recycling of the systems.

#### Energy Output and EYR

To cover a wide spectrum of influences a variety of parameters such as plant layout, operation method and behaviour of user have been selected.

The physical Energy Yield Ratio as a ratio of supplied energy to total cumulative energy is calculated using the results of (WAGNER & PEUSER, 1997):

Table 4.3.2: Energy Yield Ratio of solar hot water heaters in Germany

| | |
|---|---|
| small system | |
| SOLVIS | 8.4 to 15.1 |
| SOLAR Diamant | 9.2 to 16.5 |
| evacuated tube collector | 11.4 to 20.5 |
| big system | |
| SOLVIS | 6.6 to 11.9 |
| evacuated tube collector | 9.3 to 16.7 |

## 5 Remarks and Conclusions

- The average cumulative annual solar radiation in Germany ranges from 900 to 1200 kWh /m², whereas in India it is in the range of 1800 to 2700 kWh/m². The annual mean ambient temperatures in the two countries have a difference ranging from 5 to 20°C. The spectrums of wind energy potentials are overlapping, the best site for India has an output more than the best site of Germany, but the near coastal and inland sites of Germany are much better for wind energy when compared to similar sites in India. These differences don't permit a single generic statement regarding the technologies nor regarding the two countries.

  The energy collected by direct solar energy technologies is higher for India, although balances show that the cumulative energy demands of these systems are also higher than the values for Germany due to various reasons like difference in system layout, design specifications, maintenance requirements, etc. This has restricted the Energy Yield Ratios from being much different for the two countries as they could be for the identical system specifications.

Table 4.3.1: *CED* of solar hot water heating systems (WAGNER & PEUSER, 1997)

| | absorber system for hot water heating of one or two-family house | | | absorber system for hot water heating of multiple family house | |
|---|---|---|---|---|---|
| | small system | | | big system | |
| make | SOLVIS | Solar Diamant | evacuated tube c. | SOLVIS | evacuated tube c. |
| area [m²] | 6.15 | 5.76 | 5 | 98.4 | 78 |
| $CED_M$ [GJ] | 11.45 | 9.79 | 6.83 | 231.2 | 130.7 |
| $CED_{Assembly}$ | 10% | 10% | 10% | 10% | 10% |
| $CED_U$ [GJ] | 5% | 5% | 5% | 5% | 5% |
| $CED_{total}$ [GJ] | 13.2 | 11.3 | 7.9 | 267.0 | 151.0 |

One reason for the difference in *EYR* from solar water heating systems and photovoltaic systems is the high energy content of silicon wafers. Low conversion efficiency of the latter is another reason for the difference.

Since the photovoltaic charging system in India is designed on the basis of minimum daily radiation value, it remains under-utilised on the high radiation days. Therefore, the *EYR* is much lower than the possible EYR of a fully utilised photovoltaic system.

- For carrying out feasibility studies in addition to the $EYR_{physical}$, an *EYR* based on an equivalent primary energy output should also be considered. As is evident in the case of photovoltaic charging systems in India, looking at the $EYR_{physical}$ alone could lead to the misleading conclusion that such a system is not energetically attractive. Rather, the $EYR_{physical}$ will be close to or more than an adequate value for this system.
- The calculations of Cumulative Energy Demand and Energy Yield Ratio are not as accurate as economic cost and benefit analysis, where decimal figures have to be exact. Nevertheless, the results show clear tendencies that can be utilised for conducting a preliminary estimation of *LCA*. Therefore, both *CED* and *EYR* might be seen as indicators of environmental impacts as far as the estimation of depletion of energy sources is concerned.

The authors feel that before conducting detailed *LCA* studies, *CED* and *EYR* could provide the investigator with previous information about the criticality of parts in the lifecycle of a product.

## Table of Symbols

| Symbol | Dimension | Meaning |
|---|---|---|
| CED | MJ | Cumulative Energy Demand |
| $CED_{Assembly}$ | MJ | Cumulative Energy Demand of Assembly |
| $CED_D$, $CED_{Disposal}$ | MJ | Cumulative Energy Demand of Disposal |
| $ced_{Material}$ | MJ/kg | Specific Cumulative Energy Demand of Material |
| $CED_P$, $CED_{Production}$ | MJ | Cumulative Energy Demand of Production |
| $CED_{P,Component}$ | MJ | Cumulative Energy Demand of Component-Production |
| $ced_{Transport}$ | MJ/txkm | Specific Cumulative Energy Demand of Transport |
| $CED_T$, $CED_{Transport}$ | MJ | Cumulative Energy Demand of Transport |
| $CED_U$, $CED_{Utilisation}$ | MJ | Cumulative Energy Demand of Utilisation |
| d | km | Distance of Transport |
| EYR | – | Energy Yield Ratio |
| $EYR_{net,physical}$ | – | Energy Yield Ratio in respect to Net Physical Energy Output |
| $EYR_{physical}$ | – | Energy Yield Ratio in respect to Physical Energy Output |
| $EYR_{primary}$ | | Energy Yield Ratio in respect to the primary energy equivalent of the energy output |
| $F_P$ | – | Production-Factor |
| m | t | Transported Weight |
| $W_{el}$ | kWh | Electrical Power Output |
| $W_{net}$ | kWh, GJ | Net Power Output |
| $W_{net,el}$ | kWh | Net Electrical Power Output |
| $W_{net,\ physical}$ | GJ | Net Physical Power Output |

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